

What's Cool About Hot Stars? Infrared Observations of Cataclysmic Variables with the *Spitzer Space Telescope*

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Abstract. Cataclysmic variables have been extensively observed at optical, ultraviolet, and X-ray wavelengths, where their white dwarf primary stars and bright accretion disks dominate their emitted luminosity. Comparatively little is known about the infrared properties of cataclysmic variables. The assumption that infrared observations would reveal only the “uninteresting” secondary star has been shown to be false: recent infrared observations of cataclysmic variables have instead shown that cool dust in these interacting binaries is possibly the most important contributor to their spectral energy distributions at long wavelengths. We present recent results from infrared observations of the cataclysmic variable EF Eridani obtained with the *Spitzer Space Telescope*.

1. Dust in EF Eridani

EF Eri is a short orbital period ($P_{\text{orb}} = 81$ min) cataclysmic variable containing a strongly magnetic white dwarf ($B = 13\text{--}14$ MG). It lacks an accretion disk because of the white dwarf magnetic field, and accretion proceeds directly from the inner Lagrangian point onto the white dwarf field lines. Cataclysmic variables with this orbital period contain a very low mass, degenerate brown dwarf-like secondary star, whose mass has been whittled down during the secular evolution of the cataclysmic variable until it can no longer support fusion. The secondary star mass in EF Eri is estimated to be $0.04\text{--}0.06 M_{\odot}$ (Howell et al. 2006).

Our initial *Spitzer Space Telescope* Infrared Array Camera (IRAC) observations of EF Eri (Brinkworth et al. 2007) showed the surprising result that the mid-infrared spectral energy distribution is dominated by a non-stellar component best modeled as warm dust, most likely arranged in a circumbinary disk (see Figure 1). We report here on follow-up *Spitzer* observations using the Infrared Spectrograph (IRS).

2. Infrared Spectral Energy Distribution Models

The near- to mid-infrared spectral energy distribution of EF Eri is shown in Figure 2. Figure 3 shows physically realistic, multi-component models constructed to reproduce the observed data for EF Eri. Our modeling process is described in Brinkworth et al. (2007) and Hoard et al. (2007).

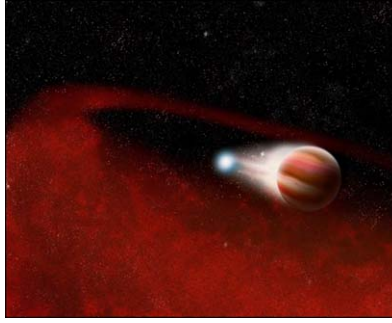


Figure 1. Artist's depiction of EF Eri, showing the magnetic white dwarf accreting via Roche lobe overflow from its brown dwarf-like companion, and surrounded by a circumbinary dust disk (see <http://www.noao.edu/outreach/press/pr06/pr0604.html>).

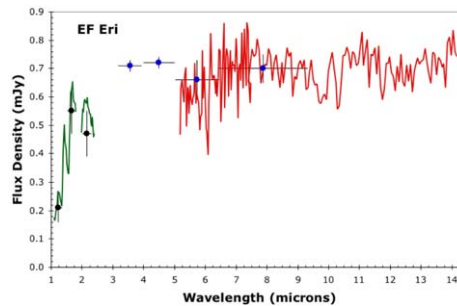


Figure 2. Spectral energy distribution of EF Eri showing the 2MASS JHK_s (black points) and IRAC 3.5–8.0 μm (blue points) photometry from Brinkworth et al. (2007), a ground-based near-infrared spectrum (green line; from Harrison et al. 2007), and our new IRS spectrum (red line). On the photometric data points, the vertical error bars are 1σ standard deviations of the flux densities; the horizontal “error bars” show the band width.

3. Results

The mid-infrared spectral energy distribution in EF Eri is dominated by emission from warm dust. *All other system components in this cataclysmic variable are negligible in the mid-infrared!*

The total mass of dust in an optically thin circumbinary disk required to produce the observed emission is $\sim 10^{18}$ kg (by comparison, the mass of the largest minor planet in our solar system, Ceres, is $\sim 10^{21}$ kg). The mass of dust in a circumbinary disk that has been predicted to be required to affect the secular evolution of a cataclysmic variable (as an angular momentum loss mechanism) is many orders of magnitude larger, $\sim 10^{26}$ kg (e.g., Taam et al. 2003).

Utilization of an arbitrary blackbody component to fully reproduce the observed spectral energy distribution is not satisfactory. However, current work is underway to resolve this in

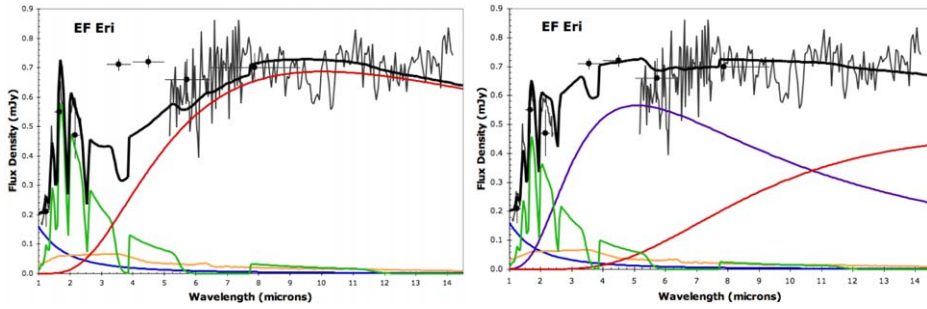


Figure 3. (*left*) Spectral energy distribution from Figure 2 with a model (thick black line) consisting of a white dwarf (represented by a 10,000 K blackbody; blue line), L5 secondary star (an empirical template constructed from 2MASS and *Spitzer* observations of low mass field stars; orange line), cyclotron emission from a $B = 13.6$ MG field (following the calculation in Channugam 1980, Thompson & Cawthorne 1987, and Schwöpe et al. 1990; green line), and an optically thin circumbinary dust disk composed of $1\ \mu\text{m}$ spherical silicate dust grains (inner edge temperature of $T_{\text{in}} = 830$ K; red line). The model does not account for some flux near $3.5\text{--}4.5\ \mu\text{m}$ (IRAC channels 1 and 2) but is otherwise a good match to the observations. (*right*) As in the left panel, but the circumbinary dust disk temperature has been decreased to $T_{\text{in}} = 450$ K, and a blackbody with $T = 1000$ K has been added to account for the missing flux at $3.5\text{--}4.5\ \mu\text{m}$ – see discussion in §3..

a more physically meaningful way. We note that the scale factor required for the blackbody component in Figure 3 (right panel) corresponds to an equivalent circular emitting area with radius of $\sim 45R_{\text{WD}}$. This is far too large to be contained in the inner binary of the cataclysmic variable, and points a finger at the circumbinary disk. Initial trials using a “two phase” disk (i.e., warm and optically thick at the inner edge, transitioning to cooler and optically thin at large radii) have shown promise in reproducing the observed spectral energy distribution shape. Additional future revisions to our circumbinary dust disk model might involve consideration of a distribution of dust grain sizes, shapes, and densities/compositions.

Acknowledgments. This research was carried out, in part, at the Jet Propulsion Laboratory, Caltech, and was sponsored by NASA through the *Spitzer* Science Center and Michelson Science Center, NOAO, and via Director’s Discretionary Time on the *Spitzer Space Telescope* awarded through the NASA/NOAO/SSC Observing Program for Teachers and Students. This work made use of data products from 2MASS, which is a joint project of the University of Massachusetts and IPAC/Caltech, funded by NASA and the NSF.

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